

Space Transportation Materials and Structures Technology Workshop

Volume I—Executive Summary

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~~Hampton, Virginia~~
~~September 23-26, 1991~~

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Space Transportation Materials and Structures Technology Workshop

Volume I—Executive Summary

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PREFACE

Space transportation materials and structures technologies have significantly advanced since most of the currently operational spacecraft and launch vehicles were designed. As the United States prepares to embark on new space missions and develop novel vehicle designs, it must make every effort to realize the potential of evolving materials and structures technologies for Earth-to-orbit, Earth-to-planet and space transfer applications. The Space Transportation Materials and Structures Technology Workshop, held in September 1991, helped to accomplish this goal by (1) developing important strategic planning information necessary to transition materials and structures technologies from laboratory research programs into robust and affordable operational systems, (2) providing a forum for the exchange of information and ideas between technology developers and users, and (3) providing senior NASA management with a review of current space transportation programs, related research and specific technology needs. The workshop provided a foundation on which the NASA and industry effort to address space transportation materials and structures technologies can grow.

The Workshop General Chairman and Co-Chairmen wish to thank all of the workshop participants who contributed their time and talent to this vital effort. In particular, we also wish to acknowledge the contributions of the key individuals who played critical roles in planning and executing the workshop.

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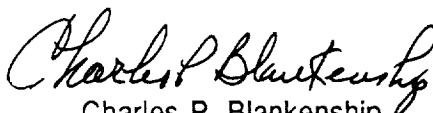
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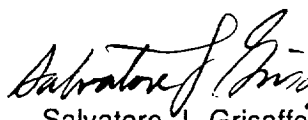
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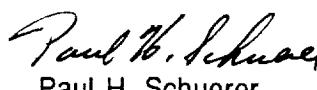
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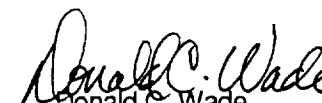
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VOLUME 1 - EXECUTIVE SUMMARY

SPACE TRANSPORTATION

MATERIALS AND STRUCTURES TECHNOLOGY WORKSHOP

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LIST OF ACRONYMS

ACC.....	Advanced carbon-carbon
ACRV.....	Advanced Crew Rescue Vehicle
ACT.....	Advanced Composites Technology
AFRSI.....	Advanced Flexible Reusable Surface Insulation
AIA.....	Aerospace Industries Association
Al-Li.....	Aluminum-lithium
ALS.....	Advanced Launch System
AMLS.....	Advanced Manned Launch System
ARC.....	Ames Research Center
ASRM.....	Advanced Solid Rocket Motor
CC.....	Carbon-carbon
CFD.....	Computational fluid dynamics
CMC.....	Ceramic matrix composites
CPAS.....	Composites Primary Aircraft Structures
CSM.....	Computational structural mechanics
CST.....	Computational surface thermo-chemistry
DoD.....	Department of Defense
DOE.....	Department of Energy
ELV.....	Expendable Launch Vehicles
ELVC.....	Expendable Launch Vehicles and Cryotanks
ET.....	External tank
ETO.....	Earth-to-Orbit
FRSI.....	Flexible Reusable Surface Insulation
GEO.....	Geosynchronous Earth Orbit
GSFC.....	Goddard Space Flight Center
JPL.....	Jet Propulsion Laboratory
JPO.....	Joint Project Office
JSC.....	Johnson Space Center
L/D.....	Lift-to-drag ratio
LaRC.....	Langley Research Center
LDEF.....	Long Duration Exposure Facility
LEO.....	Low earth orbit
LeRC.....	Lewis Research Center
LH ₂	Liquid hydrogen
LN ₂	Liquid nitrogen
LO ₂	Liquid oxygen
M&S.....	Materials & Structures
MDSSC.....	McDonnell Douglas Space Systems Corporation
MMC.....	Metal matrix composites
MSFC.....	Marshall Space Flight Center
MTS.....	Manned Transportation System
NASA.....	National Aeronautics and Space Administration
NASP.....	National Aero-Space Plane
NDE.....	Non-destructive evaluation
NDT.....	Non-destructive testing
NEP.....	Nuclear electric propulsion
NIT.....	NASA-industry team
NLS.....	National Launch System
NTP.....	Nuclear thermal propulsion
OAST.....	Office of Aeronautics and Space Technology

LIST OF ACRONYMS (cont.)

OAET.....	Office of Aeronautics, Exploration, and Technology
ORCC.....	Oxidation-resistant carbon-carbon
OSF.....	Office of Space Flight
OSSA.....	Office of Space Science and Applications
PLS.....	Personnel Launch System
PMC.....	Permanent Manned Capability
RCC.....	Reinforced carbon-carbon
RP.....	Rocket Propellant (kerosene-based)
R & T.....	Research and Technology
RV.....	Reusable Vehicles
SDIO.....	Strategic Defense Initiative Organization
SEI.....	Space Exploration Initiative
SIP.....	Strain Isolation Pad
SPI.....	Significant Performance Improvement
SSME.....	Space Shuttle Main Engine
SSTAC.....	Space System and Technology Advisory Committee
SSTO.....	Single-Stage-to-Orbit
TPS.....	Thermal Protection System
TRL.....	Technology Readiness Level
VSP.....	Vehicle Systems Panel

VOLUME 1 - EXECUTIVE SUMMARY

SPACE TRANSPORTATION MATERIALS AND STRUCTURES TECHNOLOGY WORKSHOP

Newport News, Virginia

September 23 - 26, 1991

1.0 INTRODUCTION

NASA is establishing a challenging, long-range integrated space transportation program plan built upon NASA's strong commitment to space science and exploration. In meeting the goals set forth by the evolving space transportation program, the vehicle designs developed for Earth-to-orbit, interplanetary, in-Earth-orbit, Earth/planetary entry and planetary/lunar orbit must incorporate advanced materials and structures technologies. Many of the transportation system concepts are being designed in cooperative programs between government and industry organizations. Many of the transportation system concepts involve cross-discipline technologies that require a new understanding of the relationships between traditionally independent areas such as structural design and thermal protection. The integrated nature of technology and programmatic will require new levels of multi-organizational communication and cooperation. Based on such requirements, the Space Transportation Materials & Structures Technology Workshop was sponsored by the NASA Office of Aeronautics and Space Technology (OAST) and the NASA Office of Space Flight (OSF). The workshop was held in Newport News, VA, September 23 - 26, 1991.

The Space Transportation Materials and Structures Technology Workshop provided a forum for the interchange of information between technology developers and users in order to define the future needs for space transportation materials and structures technologies. The workshop also provided an opportunity to build communication links vital to future program successes. It was the third NASA meeting on critical technology areas for space transportation. The two previous space transportation symposia addressed avionics and propulsion technologies.

The workshop was chaired by Charles Blankenship, Director for Structures, NASA Langley Research Center. Co-chairmen of the workshop were Salvatore Grisaffe, Lewis Research Center, Paul Schuerer, Marshall Space Flight Center, and Don Wade, Johnson Space Center. Thomas Crooker, OAST, Paul Herr, OSF and David Stone, OAST, comprised the NASA Headquarters organizing committee. The strong efforts of these individuals and the panel chairmen led to the success of the workshop.

To ensure that the workshop would address the broad scope of materials and structures technologies, the organizing committee created three working panels - Vehicle Systems, Propulsion Systems and Entry Systems. The Vehicle Technology Requirements Panel was also formed to present the current status of space transportation vehicle systems and to provide requirements input to the working panels.

The workshop agenda is provided in Appendix A and the workshop organization and panel structure are provided in Appendix B. The three-day workshop began in the afternoon of September 23 with introductory presentations by Charles Blankenship, LaRC; Ronald Harris, OSF; and Gregory Reck, OAST. The Vehicle Technology Requirements Panel then presented the plenary session which concluded in the morning of September 24. The working panels met separately through September 25, following presentations by Samuel Venneri, Materials and Structures Division Director, OAST, and Chester Vaughn, Office of Chief Engineer and Director Technical Integration and Analysis, OSF.

Panel summary presentations were given by the panel chairmen on the morning of

September 26, after which an open forum provided an opportunity for valuable dialogue between panel members and NASA management on technical and programmatic issues relative to materials and structures technologies.

One hundred and forty-eight individuals from the federal government and industry attended the workshop. Figure 1.0.1 lists the organizations represented.

At the time of the workshop, the Office of Aeronautics and Space Technology (OAST) was being created from the existing Office of Aeronautics, Exploration and Technology (OAET). Therefore, many of the briefing materials prepared for the workshop refer to OAET instead of OAST.

Chairman's Introduction

Charles Blankenship opened the workshop by presenting the workshop objectives. These were to:

- Identify key materials and structures technology needs for future space transportation systems.
- Assess current materials and structures technology program plan vs. space transportation needs.
- Identify voids and/or opportunities in materials and structures technology areas that have substantial benefits to advanced space transportation systems.
- Identify appropriate areas for an aggressive technology development program.
- Identify approaches to bridge the gap between technology developers and users.
- Identify mechanisms for continuation of the technology transfer process initiated at the workshop.

Meeting these objectives is necessary to maximize the payoff of materials and structures research. The fifth objective, bridging of the gap between technologists and users of technology, will only be achieved as the result of long-term collaborative efforts, and this workshop

laid the groundwork for such technology bridging by generating ideas for NASA and industry to jointly pursue.

A vital long-term goal of the workshop was to continue building strong relationships between NASA centers and industry. The role of NASA's space flight centers as customers of industry is clear, but the relationship of industry and the space flight centers as customers of NASA's research centers is not as well known. Nor has adequate attention been given to this critical linkage.

In materials and structures, as in avionics and propulsion, the technical community must develop a long-range strategic plan to ensure that those technologies needed for advanced space transportation vehicles, and which often take 10-15 years to develop, will be available when they are needed.

Office of Space Flight Perspective

Ronald Harris, Director of Advanced Flight Systems, Office of Space Flight, further discussed the challenges identified by Charles Blankenship.

Space transportation programs are more commonly established as joint efforts between both the civilian and military sectors, such as in the National Aero-Space Plane and the National Launch System programs. A national perspective must serve as the key driver in determining how to use limited resources to respond to shared interests. Commercial launch and space vehicle needs must also be addressed.

Foreign capabilities are constantly improving and must not be ignored. NASA must consider the advantages of U.S. cooperation with non-U.S. organizations possessing common interests to achieve both cost savings and improve U.S. competitiveness. The ever-growing scrutiny of the NASA budget and management structure by the Office of Management and Budget and other federal oversight groups further emphasizes the need for a healthy and competitive agency.

Cost and performance are keys to the prioritization of future technologies. The benefits of new technologies must be clearly identified to justify flight testing, which is essential for building confidence within the user community.

Office of Aeronautics and Space Technology Perspective

Gregory Reck, Director for Space, Office of Aeronautics and Space Technology, described OAST's perspective on materials and structures technologies. Gregory Reck supported Ronald Harris' views regarding the space transportation challenges facing the materials and structures community, the need for better coupling of resources and applications, and the need for communication between technology developers and users.

OAST began a rigorous review of its mission more than a year ago. It has been reviewing its products and the means by which technology evolves from the laboratory into focused programs and into the hands of system developers. The office defines its responsibility as providing technology for future civil space missions of interest to both NASA and the commercial sector. OAST must also provide a base of research and technology capabilities to support national space goals. OAST intends to incorporate commercial interests into its technology program and increase its responsiveness to commercial needs in areas such as communications satellites and launch vehicles.

In December 1990, the Augustine Committee recommended development of an externally reviewed integrated technology plan. The Augustine Committee observed that development of basic technology had been underfunded for years and recommended that higher funding levels should be provided for the future. The process which OAST used to respond to the Augustine Committee will be exercised periodically in the future to evaluate the structure and priorities of the OAST technology program. This process resulted in the identification of NASA's future mission needs and the capabilities.

Transportation technologies must address the needs of Earth-to-orbit systems as well as in-space transportation systems. Specific areas of focus include:

- Enhanced capabilities for the Space Shuttle

- Technology options for the next manned launch system
- Development of low-cost heavy-lift launch vehicles
- Development and transfer of low-cost technologies to commercial ELV's and upper stages
- Identification of high-leverage technologies for in-space transportation systems, including chemical and nuclear systems for Earth-to-orbit and interplanetary applications

Advanced materials and structures technologies can contribute significantly in each of these areas, providing durable thermal protection systems for shuttle enhancement, as well as lightweight tanks, cryogenic tank fabrication processes, and low mass space-durable materials for future space and launch vehicles. Critical to all of these efforts is an improved understanding of the space environment during long term space exposure. The Long Duration Exposure Facility (LDEF) is an important source of information on space environmental effects. LDEF data analyses and dissemination are progressing and will continue for several years.

This workshop is of critical importance in determining the activities of the highest priority and is likely to produce technologies with the highest payoffs. Cooperative ventures between NASA, the military and commercial sectors are needed.

Vehicle Technology Requirements

The plenary session on Vehicle Technology Requirements, chaired by Delma Freeman, followed the introductory presentations. This session included current information from systems studies on space transportation vehicle systems, with an emphasis on requirements that will drive future materials and structures programs and the benefits that these programs will provide.

The Vehicles Technology Requirements sessions featured the following presentations:

- *Cargo Vehicle Architecture Options* by R. Eugene Austin of Marshall Space Flight Center
- *NLS Structures and Materials* by Jack O. Bunting of Martin Marietta
- *Advanced Manned Launch System* by Theodore A. Talay of Langley Research Center
- *Advanced Crew Rescue Vehicle / Personnel Launch System (ACRV/PLS)* by Jerry Craig of Johnson Space Center
- *Single Stage to Orbit/SDIO* by James R. French of the Strategic Defense Initiative Organization
- *National Aero-Space Plane (NASP) Airframe Structures and Materials Overview* by Terence Ronald of the NASP Joint Project Office (JPO)
- *Lunar Transfer Vehicle Studies* by Joseph Keeley of Martin Marietta
- *Mars Transfer Vehicle Studies* by Gordon Woodcock of Boeing
- *Aerobraking Technology Studies* by Charles H. Eldred of Langley Research Center
- *Earth-to-Orbit Propulsion R&T Program Overview* by Steven J. Gentz of Marshall Space Flight Center
- *Advanced Rocket Propulsion* by Chuck O'Brien of Aerojet
- *Space Propulsion* by John Kazaroff of Lewis Research Center
- *Nuclear Concepts/Propulsion* by Thomas Miller of Lewis Research Center
- *Solid Rocket Motors* by Ronn Carpenter of Thiokol Corporation
- *Combined Cycle Propulsion* by Terence Ronald of NASP JPO

A discussion of each of these presentations and the complete briefing charts will be contained in Volume 2 of these proceedings.

Figure 1.0.1

Space Transportation Materials & Structures Technology Workshop Summary

NASA *OAST/OSF*

- A forum for the interchange of information between technology developers and users, in order to define the future needs of space materials and structures technologies for the research and development community
- 148 Participants Representing:

Government

- Los Alamos National Laboratory
- NASA Ames Research Center
- NASA Headquarters
- NASA Johnson Space Center
- NASA Langley Research Center
- NASA Lewis Research Center
- NASA Marshall Space Flight Center
- National Aerospace Plane - Joint Program Office
- Oak Ridge National Laboratory
- Sandia National Laboratory
- Strategic Defense Initiative Organization
- U. S. Army Missile Command
- Wright Laboratory

Industry

- Aerojet
- Alcoa
- Atlantic Research Corporation
- Babcock and Wilcox
- Boeing
- General Dynamics
- Grumman
- Hercules
- ICI Fiberite
- Lockheed
- LTV
- McDonnell Douglas
- Martin Marietta
- Pratt & Whitney
- Reynolds Metals
- Rocketdyne
- Rockwell
- Thiokol
- Westinghouse
- United Technologies

2.0 FINDINGS AND RECOMMENDATIONS

The efforts of the workshop participants led to the identification of a number of important findings and recommendations, and these are discussed in this section.

2.1 VEHICLE SYSTEMS PANEL

The Vehicle Systems Panel addressed materials and structures technology issues related to launch and space vehicle systems not directly associated with the propulsion or entry systems. The Vehicle Systems Panel was comprised of two subpanels - Expendable Launch Vehicles & Cryotanks (ELVC) and Reusable Vehicles (RV). Tom Bales, LaRC, and Tom Modlin, JSC, chaired the expendable and reusable vehicles subpanels, respectively, and co-chaired the Vehicle Systems Panel. The Vehicle Systems Panel started with a plenary session in which the following papers were presented:

- "Net Section Components for Weldalite™ Cryogenic Tanks," by Don Bolstad
- "Built-up Structures for Cryogenic Tanks and Dry Bay Structural Applications," by Barry Lisagor
- "Composite Materials Program," by Robert Van Siclin
- "Shuttle Technology (and M&S Lessons Learned)," by Stan Greenberg

The first two presentations provided a perspective on the current state of the art in aluminum-lithium (Al-Li) alloys technology, especially with regard to Advanced Launch System (ALS) applications. The third presentation identified the status of composite technologies for space applications and stressed both technology and programmatic / cultural issues associated with composites technology development efforts ongoing in the U.S. The last paper identified many of the materials and structures issues that arose as a result of Space Shuttle program experience. These papers are included in Volume 2 of these proceedings.

2.1.1 Expendable Launch Vehicles and Cryotanks Subpanel

The Expendable Launch Vehicles and Cryotanks Subpanel had the following perspectives:

- *New Materials Provide the Primary Weight Savings For Vehicles*
 - Provide robustness in design
 - Yield systems cost savings
- *Current Investment*
 - Disproportionately small
 - Significant benefits are apparent
 - Absence of focused materials and structures technologies within NASA for launch vehicles
- *Typically 10-20 Years to Mature and Fully Characterize New Materials*
 - Manufacturing processes must be developed concurrently
 - User needs can accelerate materials development
 - Selected examples: Al-Li 8090 and 2219

The Expendable Launch Vehicles and Cryotanks Subpanel clearly recognized that the cost of characterizing a materials system could become extremely expensive and could not be accomplished without anticipation of a future application. The panelists agreed that only a limited number of materials systems would be matured for aerospace applications. The panel concentrated on the processing and fabrication issues associated with demonstration of low fabrication and assembly costs. Concern was expressed as to whether certain systems would receive the support necessary to fully characterize them for these applications. Another concern was the evolution of advanced inspection methods that become more critical with more complex materials.

The subpanel identified the priority technical issues shown in Table 2.1.1.

Table 2.1.1 Priority Technology Issues for Expendable Launch Vehicles & Cryotanks

1. Advanced structural materials
2. Al-Li technology
3. Near-net shape fabrication technology for vehicle structures
4. Near-net shape metals technology
5. Near-net shape extrusions for structural hardware
6. Near-net shape forgings
7. Near-net shape spin forgings
8. Welding
9. In-space welding/joining
10. Composites technology for cryotanks and dry-bay structures
11. Joining technology for composite cryotanks
12. Tooling approach for manufacturing large diameter cryotanks
13. Develop a cure methodology for large composite cryotanks
14. State-of-the-art buckling structure optimizer program
15. State-of-the-art "shell of revolution" analysis program
16. NDE for advanced structures
17. In-line inspection of composites
18. Scale-up of launch vehicles
19. Launch vehicle TPS/insulation beyond 27.5 ft. diameter
20. Design and fabrication of thin-wall cryotanks for space exploration (5-20 ft. dia.)

Priority concerns of the Expendable Launch Vehicles and Cryotanks Subpanel were identified as:

1. The primary near-term issue regarding Al-Li is availability of funding to ensure incorporation in the National Launch System.

- Production capability is in place for 8090, Weldalite and 2090 Al-Li alloys
- Near-net shape processes have been defined; scale-up activities are underway
- Program management decisions are required to exploit the potential of Al-Li alloys

2. NASA materials technology programs should include research on expendable launch vehicles and cryotanks.

- A focused materials and structures technology program for launch vehicles is necessary.
- Sustained programs to support user needs and long-term NASA missions are clearly needed.

3. Structural analysis and optimization, computational methods and experimental verification, particularly for long duration and complex space environmental conditions, are needed.

4. Non-destructive evaluation (NDE) techniques and methods must be exploited to assure integrity, reliability and cost reductions.

5. Joining and bonding techniques and concepts must be developed and characterized for future large launch vehicle applications.

2.1.2 Reusable Vehicles Subpanel

In creating a list of highest priority issues, the subpanel's primary framework for discussion was future reusable vehicles requirements. The four most pertinent requirements for reusable vehicles were defined as low cost, high reliability, low maintenance and on-time launch or deployment capability. However, current technology gaps inhibit the achievement of these future vehicle goals.

The RV subpanel identified several technologies required for envisioned and

existing missions and vehicle programs, as shown in Table 2.1.2.

Table 2.1.2 Priority Technology Issues for Reusable Vehicles

1. Cryogenic tankage
2. Cryogenic tankage with LH₂
3. Cryogenic tankage with LO₂
4. Launch vehicle TPS/insulation
5. Durable passive thermal control devices and/or coatings
6. Development and characterization of processing methods to reduce anisotropy of material properties in Al-Li
7. Durable thermal protection system
8. Unpressurized Al-Li structures (interstages, thrust structures)
9. Near net shape sections
10. Pressurized structures
11. Welding and joining
12. In space joining
13. Micrometeoroid and debris hypervelocity shields
14. State-of-the-art shell buckling structure optimizer program to serve as a rapid design tool
15. Damage tolerant design for composite structures
16. Test philosophy
17. Reduced load cycle time
18. Optimized system engineering approach to ensure robustness
19. Structural analysis methods
20. Optimization of structural criteria
21. Develop an engineering approach to properly trade material and structural concepts selection, fabrication, facilities and cost
22. Maintenance and refurbishment philosophy

The priority concerns of the Reusable Vehicles Subpanel included:

1. *Although several Al-Li alloys are currently under development, specific knowledge about any one alloy has not progressed to a point where a vehicle designer can safely baseline Al-Li for any application.*

2. *The benefits of composites for cryogenic tanks warrant continued research in this area, however, issues including penetration effects (sealing), H₂ compatibility (liners), and H₂ leakage must be priorities for research.*

3. *The potential of composites for LO₂ tanks and the primary issue of flammability protection were discussed.*

4. *Metal matrix composites (MMC's) are being studied by the NASP program, especially titanium based composites, because of their potential hot structure applications. MMC properties must be better characterized.*

5. *Advanced thermal protection system materials are needed which are durable, lightweight and can be used in a range of erosion environments.*

6. *For actively cooled structures, innovative structural designs are needed to lower structural weight and improve cooling effectiveness.*

7. *Fabrication techniques discussion focused primarily on Al-Li. For Al-Li alloys such as 2090, technology is lacking in cryotank manufacturing areas including stretch-forming gores, spur domes and large-scale extruded net sections.*

8. *Test philosophy for advanced structures technologies should include a strong commitment to test structures to failure.*

9. *Space vehicle developers should perhaps look to non-space industry philosophies to realize lessons learned.*

2.1.3 Vehicle Systems Panel Conclusions

In summary, the conclusions of both subpanels emphasized Al-Li materials, composites, and fabrication and manufacturing technologies. These technologies will require additional funding to reach maturation, as well as the development of new analytical methods and non-destructive evaluation (NDE) techniques.

2.2 PROPULSION SYSTEMS PANEL

The Propulsion Systems Panel was established to address the specialized nature of the materials and structures technology issues of propulsion systems. This panel was co-chaired by Carmelo Bianca, MSFC, and Bob Miner, LeRC. Because of the diverse range of missions anticipated for the Space Transportation program, three distinct propulsion system types were identified in the workshop planning process: liquid propulsion systems, solid propulsion systems and nuclear electric/nuclear thermal propulsion systems. Three subpanels, one for each of these propulsion system types, were created.

2.2.1 Liquid Propulsion Systems Subpanel

The Liquid Propulsion Systems Subpanel was chaired by Larry Johnston, MSFC. Advancement in materials technology and structural analysis capability for liquid propulsion systems has been a recognized technology need for many years. During the development of the high-performance, high-pressure, reusable Space Shuttle Main Engine (SSME), the fact that the design and analysis tools used for engine designs in the 1950's and 1960's were inadequate for determining actual component design margins became increasingly clear, and the tools used to predict component operating life in advanced engine designs such as the SSME were pushing the state of the art. As a result, the predicted service life of the SSME has never been achieved. Earlier engines were typically low pressure, expendable designs with short service-life requirements (minutes instead of hours) and apparently had more than

adequate (though actually unknown) design margins due to the relatively benign environments in which engine component parts were required to operate.

The need for new materials and better structural designs to tolerate the hostile internal environments that components are likely to encounter in future engine designs also became apparent. Additionally, to help reduce space transportation operations costs, innovative manufacturing processes will be needed to significantly reduce hardware production times and cost and enhance hardware quality and reliability. For expendable launch vehicle systems, such as the projected National Launch System (NLS), minimum production costs are paramount since the propulsion system will be discarded every flight. In contrast, for reusable transportation systems such as Advanced Launch Manned Systems (AMLS) or Single-Stage-to-Orbit (SSTO) vehicles, low production costs are important, but must be tempered with extended service life requirements.

The Liquid Propulsion Subpanel stated findings and recommendations on the base R&T program and on technologies considered peripheral. These stressed the need for a long-range technology plan and aggressive technology transfer.

In summary, the subpanel commented that a complacency problem exists, in which project management believes that materials and processes will be there when needed. Also, organizations tend to favor familiar materials, a situation which is exacerbated efforts. Since technologies and priorities which emerge from this workshop represent a current snapshot, a mechanism should be provided for a periodic update.

2.2.2 Solid Propulsion Systems Subpanel

The objective of the Solid Propulsion Subpanel, chaired by Raymond Clinton, MSFC, was to assess the state of the art in solid propulsion materials, structures and manufacturing processes, compare this to needs identified prior to and during the plenary session of the workshop, and determine the areas where additional technology effort should be expended to meet these needs.

The Solid Propulsion Subpanel divided into ten task teams representing each of the basic elements of solid rocket motors. These task teams were 1) motor cases, 2) propellants, 3) nozzles, 4) bondlines, 5) nondestructive evaluation, 6) motor case insulation, 7) materials properties, 8) analysis, 9) adhesives, and 10) hybrid motors.

The task teams prepared inputs prior to the workshop regarding the state of current technology and the needs in each of the ten areas. As a result of this thorough assessment of current technology and future propulsion system needs, a preliminary determination of the technology required to satisfy these needs was completed. A total of 90 technology needs were defined by the task teams. In the order of greatest number, these were bondlines - 25; analysis - 14; propellants - 13; nozzles - 8; NDE - 7; motor case insulation - 6; materials properties - 6; motor cases - 5; adhesives - 4; and hybrid motors - 2. The Liquid Propulsion Subpanel added to this list four additional needs in NDE and motor cases. After review and combination of the needs, the following list resulted: 1) bondlines/propellant - 42; 2) nozzles - 28; 3) motor cases - 11; 4) motor case insulation - 7; 5) hybrid rocket propulsion - 2.

Presentations in the following areas in which additional technology effort was determined to be needed were made:

- Motor cases
 - Improved case materials/forms
 - Improved case joints/attachments
 - Self insulating case
- Propellant/Bondlines
 - Material and process variability
 - Bondline design for inspectability
 - Propellant and bondline failure criteria
 - Propellant test techniques
- Insulation
 - TPE insulator fabrication technology and bondline characterization for large motors
 - Bondline design methodologies

- Nozzles
 - Process understanding, optimization and control for ablative nozzle components
 - Robust ablative nozzle material and process development
- Analytical issues
 - Material response characterization and constitutive modeling of ablative materials
- Hybrid propulsion
 - Hybrid propulsion feasibility demonstration

2.2.3 Nuclear Propulsion Systems Subpanel

The Nuclear Propulsion Subpanel was chaired by Bob Miner, LeRC, and co-chaired by James Stone, LeRC. The subpanel meetings began with presentations on Nuclear Thermal Propulsion (NTP) and Nuclear Electric Propulsion (NEP) systems and materials. The titles and authors of the presentations were

- "Fuels Development for Nuclear Propulsion Systems," by Bruce Matthews, Los Alamos National Laboratory
- "Materials for Space Nuclear Thermal Propulsion Systems" and "Refractory Alloys for Space Nuclear Electric Propulsion Systems," by Roy Cooper, Oak Ridge National Laboratory
- "Fuel Materials Issues Involved in the Development of Nuclear Thermal Rockets" and "Non-Fuel Materials Issues Involved in the Development of Nuclear Thermal Rockets," presented by Robert Long, Babcock & Wilcox

The primary driving force behind renewed interest in space nuclear propulsion is SEI. The Stafford Synthesis Group labeled nuclear thermal propulsion an enabling technology for SEI. During 1991, an interagency (NASA / DOE / DoD) technical panel evaluated nuclear thermal propulsion concepts as well as planned a joint technology development project in nuclear propulsion. The present plan calls for demonstrating Technology Readiness

Level (TRL) six for NTP and TRL five for NEP by the year 2006.

Table 2.2.1 outlines the Nuclear Propulsion Subpanel findings and recommendations.

The workshop participants also generated a prioritized list of material systems development tasks, as shown in Table 2.2.2. Enabling technologies are marked with an "E" and those that provide a significant performance improvement are denoted by "SPI". Those that are not

labeled would provide marginal improvements in performance.

The issues related to NTP and NEP must be addressed by the materials and structures research community if the objectives of SEI are to be met in accordance with the recommendations of the Stafford report and the current intentions of NASA.

FINDINGS

- Operating conditions likely to be significantly outside current experience
- Multiplicity of uncertainties effect durability
- Large number of materials might be considered for various components
- Critical materials are not available
 - No longer produced
 - In laboratory development
 - In conceptual stage only
- Funding precludes concurrent development of many candidates

RECOMMENDATIONS

- Ensure concurrent engineering between system design and materials development
- Ensure minimal duplication in qualification of materials between different programs and contractors
- Ensure advanced design methodology/validation is included early to assure a high-performance, durable, and safe design

Table 2.2.1. Nuclear Propulsion Subpanel Findings and Recommendations

ISSUES/TECHNOLOGY REQUIREMENTS

- NTP Fuels/Coatings (E)
- NEP Refractory Alloys (E)
- NEP Fuels (E)
- NEP Radiator Materials (E)
- NTP Nozzles (SPI)
- Turbopump Materials (SPI)
- Lightweight Tankage/Insulation (SPI)
- High-Temperature Thermal & Electrical Insulation (SPI)
- Pressure Vessels (SPI)
- Non-Fuel Coatings (SPI)
- High-Temperature Seals
- Neutronic Control Materials
- Lightweight Radiation Shielding
- Radiation Hard, High Temperature Electronics

E: Enabling SPI: Significant Performance Improvement

Table 2.2.2. Nuclear Propulsion Subpanel Issues and Technology Requirements

2.3 ENTRY SYSTEMS PANEL

The Entry Systems Panel, chaired by Don Rummler, LaRC, and Dan Rasky, ARC, considered subdividing into separate subpanels for (1) Earth-to-orbit / orbit-to-Earth missions and (2) Earth-to-planetary / planetary-to-Earth missions, but commonality of technical issues led to the panel's decision to work together.

Although encouraged in the plenary session to develop more generic R&D programs similar to the CPAS (Composites Primary Aircraft Structures) and ACT (Advanced Composites Technology) efforts in the aeronautics program, the panel conceded that entry systems technology could not be easily separated from specific mission requirements because of such factors as heating peak and duration / total heat load, ground versus on-orbit assembly, and reuse requirements.

An important general finding was that *a family of TPS is needed for both optimum vehicle performance and varying vehicle mission requirements*. The Shuttle Orbiter has used metallics, several types of ceramic, carbon-carbon TPS, and, on some early flights, ablators in areas of uncertain high heating rates. Vehicles subject to the more severe heating environments expected for planetary entry missions will require advanced ceramics and carbon-carbon materials and/or ablators.

Flight testing was identified as a critical need for aeroassist vehicles to resolve discrepancies in various methods for calculating heating loads, demonstrating on-orbit assembly deployment, and validating new TPS technologies.

A lesson learned from Shuttle experience is *the need to document the development history as design drivers, such as loads, change during*

the course of vehicle design, and as various implementation issues not addressed by R&D efforts are met and resolved. Though research activities and technology advancements are adequately documented, the development history, perhaps equally important for designers of future vehicles, is typically not documented in either archival publications or readily-accessible company reports and it is eventually lost due to attrition of key personnel.

Another lesson learned is that test results are not always adequately analyzed or completely encompassing of all failure modes. The panel also noted that materials data are not readily available in a certified, maintained and accessible data base. Discussion also indicated the manner in which technology transfer occurs in both directions between the U.S. and other countries. Therefore, several materials and structural concepts must be investigated and developed

to accommodate the significant variations in the space transportation missions currently being considered by NASA.

2.3.1 Technology Needs

Three key technology drivers for all anticipated vehicles were identified:

- Improved TPS performance for safety / reliability
- Lower operating costs
- Increased vehicle capability and supportability

These technology drivers lead to the identification of fourteen high-payoff technology needs in four areas, which are shown in Table 2.3.1.

1) New/Improved TPS materials and concepts	
• Metallics	• Flexible ceramics
• Toughened ceramics	• Advanced carbon-carbon
• Ablators	• Special TPS components
• TPS/Structural integration	• Water-based composite TPS & structures
2) Inspection and certification	
• Inspection, NDE, and smart materials	
• Simplified certification/recertification	
3) Specific needs for planetary missions	
• Environmental compatibility	
• On-orbit activities	
4) Improved test and analysis compatibility	
• Test facilities	
• Interdisciplinary modeling codes	

Table 2.3.1 High-Payoff Technologies for Entry Systems

2.3.2 Entry Systems Panel Conclusions

Pursuit of the fourteen technology items described is recommended in order to lead to the goals identified in Table 2.3.2.

To reach these goals, the following points must be realized:

- Technologists tend to overlook mundane problem areas, which is why problems

such as accessibility to equipment and structures for inspection and servicing, weatherproofing of TPS, and extensive checkout operations still exist.

- A gap between technology products and program needs often exists. Advanced development programs should be supported (funded) to bridge this gap, or the technologist should make his products readily accessible by the system developer and the system user.
- Cultural and programmatic barriers to efficient technology transfer exist. Responsible and dedicated NASA-wide

working groups are recommended. A step in this direction was the Ames - Johnson group effort on RSI and the Langley - Johnson group effort on carbon-carbon, but technology transfer can still be improved, especially before NASA commits to a project.

- Entry systems test facilities in the U.S. are aging and must be upgraded. Flight test facilities are also needed.
- Certification for space-based/long duration flight entry systems will be a major issue and our current methodology must be augmented to accommodate it.

- New, very high temperature ceramic matrix composites/TPS for 4000+°F reusability (Zr and Hf ceramics)
- High strength ceramic matrix composites for structural TPS applications at 3000+°F (SiC/TiB₂) matrix ceramics
- Durable, lightweight ceramic TPS for 3000+°F use
- Lightweight, rigid ceramic insulations for 3000+°F use
- Flexible lightweight ceramic insulations/TPS for 2500+°F use
- New very lightweight ablators with 20-30% weight savings compared to state-of-the-art materials
- High emissivity, low surface catalytic efficiency, and reflective coatings for advanced TPS
- New 3-D computational surface thermochemistry (CST) code for predicting detailed near-surface fluid/material response interaction for advanced TPS/vehicle analyses

Table 2.3.2 Entry Systems Major Goals

2.4 OPEN FORUM

Following the summary presentations by the chairmen of the three panels, NASA management addressed the issues raised. This section summarizes the comments of Robert Davies, OSF Advanced Program Development Division; Samuel Venneri,

Director, OAST Materials and Structures Division; Marion Kitchens, OSF Unmanned Launch Vehicles and Upper Stages Division; Salvatore Grisaffe, Materials Division Chief, LeRC; and Charles Blankenship, Director for Structures, LaRC.

Robert Davies, OSF Advanced Program Development Division

The Office of Space Flight sponsors three types of advanced development programs:

- Studies of advanced concepts and their technology requirements involving interaction with the Office of Aeronautics and Space Technology to focus on potentially feasible concepts for long-term applications.
- Advanced development programs which lead to ground demonstrations

- Flight demonstrations

The workshop participants must duplicate the success achieved by the previous space transportation avionics and propulsion technology symposia by sustaining the momentum developed by this initial meeting. This is especially important for OSF because it is currently involved in only a few materials development efforts. The panels recommended several advanced development efforts that the Advanced Program Development Division could apply to expand its efforts.

In summary, the workshop participants performed an excellent job and produced a very impressive set of results. The dialogue established during the workshop should prove to be very beneficial to future activities.

Samuel Venneri, OAST Director of the Materials and Structures Division

NASA and industry must cooperate effectively to realize the full potential of advanced materials and structures to meet the needs of future spacecraft.

To most effectively use the information produced by the workshop, additional effort is required. Recommendations must be prioritized and packaged to illustrate how proposed efforts will benefit system performance. A complete story is needed that explains the current state of the art of relevant technologies, future system requirements, ongoing programs to address these requirements, existing gaps, and proposed new efforts to bridge these gaps without duplicating existing research and development projects. Without a clear and logical rationale to support them, workshop recommendations will be impossible to implement.

In the past, introducing advanced materials and structures technologies into the design of new spacecraft has been difficult. In terms of in-house research capability, NASA's centers are the government's best laboratories and their research and development activities must continue to emphasize long-term research needs. Establishing and maintaining a long-term focus is also essential to avoid the crisis

management that too often interferes with an optimal allocation of resources.

NASA must emphasize integrated research and development efforts, and it must recognize that timeliness and efficiency are important goals of new programs.

Current practice in the development of new aeronautics technology is a good example of how NASA should conduct its research and development efforts. Although aeronautics has only two primary centers, Langley and Lewis Research Centers, the comparatively larger infrastructure of space technology can learn from the experience of aeronautics. LaRC concentrates on advanced airframes, while LeRC specializes in new engines; the centers understand their roles and work very well together. They develop and execute projects with a "skunk works" mentality that requires very little management structure.

NASA is currently making a concerted effort to define its space strategy. For instance, the Office of Space Science and Applications has a strategic plan that specifies its overall objectives and goals. Although implementation of this plan would require a greatly increased budget, it serves as a roadmap and reference point for planning future activities. Similarly, the Office of Aeronautics and Space Technology is defining a strategic plan for materials and structures research and technology. This plan is intended to satisfy the needs of potential users of advanced materials and structures within both NASA and industry.

NASA's materials and structures community must develop the ability to transfer technology to industry. Industry interaction is essential to the future success of materials and structures programs and NASA. The task before the materials and structures community now is to determine how to make inroads into the system in order to develop needed technologies. Following is a discussion of key technology areas.

Expendable Launch Vehicles

Expendable launch vehicles (ELV's) will require applications of advanced materials and structures technologies. OAST would appreciate industry's assistance to fully understand industry's perspective on the capital equipment issue, which is a major

barrier to the insertion of technology. Inputs from space system primes regarding investment and alternatives for machining hardware for use in future ELV's is particularly needed.

Reusable Launch Vehicles

Regarding the issues raised on non-destructive evaluation and launch philosophy, possibly a small research program on smart materials and structures could focus on recertification. A top-down analysis by industry is needed to justify a low-level research effort to investigate this area. In conjunction, NASA and industry must benefit from the experience of international aerospace efforts, for instance, Soviet experience with Al-Li fabrication.

Nuclear Propulsion Systems

The potential difficulty of meeting the high temperature material performance requirements associated with some nuclear power conceptual designs is a concern. System designers must be very careful not to assume that advanced materials able to satisfy unprecedented operating temperatures will be available when needed. To a certain extent, allowing materials development to guide system design may be advised.

Industry can help by identifying key issues in nuclear propulsion and ensuring that proposed research activities take full advantage of prior nuclear propulsion research and development sponsored by the Department of Energy. Although the government is investing resources in the demonstration of the SP-100 space nuclear power system, whether the SP-100 program is using materials of greatest interest to potential nuclear propulsion systems is not certain.

Solid Propulsion Systems

Initiating new materials research programs for nozzles and other solid propulsion system components is very difficult. Much of the research performed in this area has originated in the Office of Space Flight, which seems to most clearly recognize the need for such research. Industry help is needed to demonstrate the high payoff of advanced materials and

structures in terms of performance and safety. Payoff of advanced materials and structures may be best illustrated through a clean sheet approach to new vehicle design to derive system requirements and thereby show the benefit of meeting these requirements with new technologies.

Entry Systems

Some correlation is evident in ablative materials research for entry systems and propulsion systems. A possible solution might be a fundamental level program to characterize ablative materials for a number of applications.

NASA's strategic plan for space technology is critical to the investigation of materials and structures technologies for aerospace applications. Sub-scale demonstrations of new technologies will be needed to transfer them into operational programs. Input from industry is highly needed to complement and expand upon the workshop results.

Marion Kitchens, OSF Unmanned Launch Vehicles and Upper Stages Division

Marion Kitchens strongly emphasized the importance of Samuel Venneri's discussion. He stressed that it is the responsibility of NASA and industry, at the individual level, to ensure that the efforts of this workshop are carried forward.

Salvatore Grisaffe, Materials Division Chief, Lewis Research Center

Salvatore Grisaffe observed that certain material systems had been frequent topics of discussion in the course of the workshop. These material systems included high-temperature refractory metals, carbides, lightweight low-temperature structural materials for solid rockets and large space vehicles, aerobrake and thermal protection system materials, ceramic matrix composites and solid rocket fuel materials. These material systems share the need for:

- Improved design methodology for reduced weight and built-in inspection
- Improved fabrication methods to lower cost

- Validation methodologies involving ground-based test beds to improve small component-level testing

As discussed earlier, one potential strategy to achieve materials and structures goals would be to leverage the existing progress made by aeronautics research and development programs. For instance, aeronautics applications of metal and ceramic matrix composites are currently being studied. With an additional small level of funding from space technology, space requirements could be studied as part of the same effort.

An overlap of research efforts between NASA and industry is evident. Elimination of duplication is critical, especially in consideration of budget constraints. Technology funding is growing more difficult to obtain, and the materials and structures community must cooperate in solving problems and pursuing new technologies.

Charles Blankenship, Director for Structures, Langley Research Center

Charles Blankenship expressed his appreciation to NASA and industry representatives for participating in the workshop and contributing to the development of more effective NASA programs. One key event currently underway for the first time is the formation of a strategic long-range plan by both the Office of Aeronautics and Space Technology and the Office of Space Flight. The draft plans of both offices are under review. The organizers of the workshop intend to use the workshop results to influence and strengthen the high priority technology areas discussed in the strategic plans as well as the rationale behind them.

3.0 CONCLUSIONS

The findings and recommendations summarized in this section should provide an effective tool to further develop advanced materials and structures technologies for evolving space transportation systems. Because of the dynamic nature of materials and structures technologies as well as space transportation plans, the directions taken from these conclusions should be

reevaluated over time as they are implemented.

The workshop participants confirmed the need to understand and apply new materials and structures technologies for Earth-to-orbit, Earth-to-planet and space transfer applications. More detailed information is provided in the individual panel reports (Sections 2.1-2.3) and on the charts presented in Volume 2 of the proceedings.

Current Capabilities and Future Plans

For the U.S. to improve the reliability, operability and affordability of its national space transportation system, both in absolute terms and relative to the strengthening international capabilities, an improved space materials and structures technology base and systems capability is vital. Unfortunately, characterizing and maturing new materials in the current U.S. system typically takes 10-20 years. Timeliness and efficiency must be recognized as important goals of technology development programs.

Resolving these problems is a major challenge. Manufacturing processes should be developed concurrently with materials development and testing to the extent possible in order to reduce the total development schedule for new materials and structural concepts. Also, increased levels of effort are needed in specific areas such as fabrication and manufacturing technologies for Al-Li and other metallics, composites, and ceramics which are suitable for advanced structural concepts, propulsion systems, seals, coatings, ablators and other thermal protection system elements. Non-destructive evaluation and inspection techniques, compatibility of new materials, and vehicle design, analysis, integration, testing, certification and recertification facilities and methods are also important topics which need more emphasis in order to satisfy mission requirements for future space vehicles. Future activities should also consider how to benefit from and encourage the development of performance-enhancing technologies that are not clearly within the purview of materials and structures. *Virtually every panel emphasized the need for greater efforts*

in every phase of the development cycle for new materials and structural concepts.

Strategic Planning

A national space materials and structures strategic plan is needed to help meet the requirements of near-term and future space transportation systems for advanced materials and structures. Such a plan would serve to provide focus and direction for future materials and structures research and development activities, in part by emphasizing the need for integrated research and development efforts. The materials and structures strategic plan should define alternatives for improving the planning, development, testing, verification, and transfer of space transportation materials and structures technologies from developers to users. The goal of the planning process should be to prepare a unified national plan which key public and private organizations will actively support. Funding will be necessary to bring the plan to fruition.

Several sources of information are available to assist in the strategic planning effort. For example, the Aerospace Industry Association has drafted a report entitled *Key Technologies for the 90's* that addresses ways to incorporate composite technologies in the fabrication of space structures. The AIA is also developing a National Composites Strategic Plan.

Lessons Learned

Lessons learned from past materials and structures development and application programs, aerospace and non-aerospace, must be intelligently applied to future programs. New materials and structures technologies may enable the use of new, effective engineering and management techniques.

Materials for Future Vehicles

More than any other new technology area, advanced materials offer the potential to significantly reduce the size and mass of launch vehicle structures and components. Nonetheless, the current materials and structures research and development effort is disproportionately small, particularly with regard to the development of technologies with focused launch vehicle applications. Material systems of

particular interest include high-temperature refractory metals, carbides, lightweight low-temperature structural materials for solid rockets and large space vehicles, bearing materials, aerobrake and thermal protection system materials, ceramic matrix composites and solid rocket fuel materials.

Space vehicles, especially those that must repeatedly survive the rigors of reentry, face extremely harsh operating environments. As a result, these vehicles will typically require a family of structural and thermal protection materials to meet all vehicle performance and lifetime requirements. For this reason, and because it is very difficult to separate technology requirements from specific mission requirements, a range of materials and structural concepts must be developed and investigated.

Design Drivers

System development programs sometimes rely on projections of past improvements in material performance as a basis for assuming that currently unavailable materials and processes will be available when needed. Developing appropriate criteria for selecting and prioritizing research efforts to ensure that needed technologies will, in fact, be available on schedule is necessary. System safety, cost, performance and reliability are all important, but more detailed guidance is required to direct the path of materials and structures research. One approach would be to assess subsystems and components of future propulsion systems to determine critical materials and structures performance and compatibility requirements. Effective technology management is impossible without an accurate knowledge of the origin and *evolution* of design drivers. Performance specifications often change during the course of vehicle design, and these changes must be transmitted to appropriate research and development activities.

Flight Testing

Flight testing is a key aspect of the validation effort which must occur prior to new technology transfer to operational systems. This is especially true for concepts such as aeroassisted vehicles, which require flight testing to validate design and

analysis tools. In addition, flight testing is important to verify the feasibility of thermal protection system concepts for large planetary space vehicles that require in-space deployment and/or servicing.

Operational Issues

Research and development efforts tend to emphasize the use of advanced technologies to further the state of the art. Greater emphasis is needed on engineering solutions to less exotic, but nonetheless very important operational issues such as equipment accessibility, inspection, servicing, and pre-launch checkout procedures.

Joint Efforts

Efficiency is achieved when departments, branches and agencies of the federal government coordinate parallel and complementary development programs. An aggressive program to establish technology sharing agreements between NASA, SDIO, the Air Force, industry and other organizations would pay large dividends. For example, aerospace applications of materials such as metal and ceramic matrix composites could be cost effectively studied by expanding upon ongoing aeronautics research and development efforts.

Technology Transfer

NASA should study ways to formalize the technology transfer process by promoting more interaction between technology developers, project managers and chief engineers in the government and industry. Especially important is the need for effective transfer of technology from the NASA research centers to the NASA development centers.

Furthermore, technologists should be used as an internal consulting resource when technical problems arise, and operational considerations should be more visible in the review process used to evaluate research activities and establish lists of needed technologies. Effective communications are obviously very important, and events such as this workshop help to establish and build the informal relationships between technology developers and users. Equally

important are the interactions between technology developers, prime contractors and their subcontractors.

4.0 CONTINUING ACTIVITIES

A long-range goal of the materials and structures community must be to ensure that advances in the state of the art are incorporated into the design of operational spacecraft and launch vehicles. The Space Transportation Materials and Structures Technology Workshop was the initial step in the identification of materials and structures technology needs for the Space Transportation program and the definition of how current efforts can best meet these needs. However, realizing the full potential of new technologies will require a long-range plan and a continuous long-term commitment to the plan in the form of research activities consistent with the plan's objectives.

The previous space transportation technology symposia for avionics and propulsion were also initial steps in meeting long-term technology development objectives for other disciplines. The results of these symposia and the follow-on activities that have evolved should provide an experience base from which NASA materials and structures managers can create the most effective effort to continue to sustain the momentum developed by this workshop. As the first phase of continuing activities, an initial planning meeting of key NASA personnel should be convened to discuss alternatives for future action. The proposed planning meeting should include a discussion of the merits of establishing ad hoc committees to address early action on tasks such as prioritization, strategic planning and communication.

Prioritization

The recommendations produced by the workshop should be reviewed and prioritized. High-priority recommendations should then be packaged to illustrate how proposed efforts will benefit specific mission applications in terms of system performance, cost, risk, etc. The product of this effort should include a discussion of the current state of the art of relevant technologies, future system requirements, areas where existing programs fail to adequately address these requirements, and

how proposed new efforts can fill these gaps. This should produce a clear and logical rationale for program managers to support implementation of workshop recommendations.

Strategic Planning

A long-range strategic plan for materials and structures research, development and application could be an extremely useful tool for NASA management as they respond to changing requirements for a strong and affordable national space transportation infrastructure. Inherent within the strategic plan should be clear direction on its effective implementation. Some of the key factors that should be considered in the planning process are

- A comprehensive representation of the national space transportation infrastructure and the supporting systems that will be required into the next century
- A critical and comprehensive evaluation of current national space transportation capabilities, plans and activities
- A timetable for those technological advancements that are critical to the national space transportation infrastructure of the future
- Retention of current capabilities while building our national technical expertise in space transportation
- A summary of "cultural changes" necessary for improving the effectiveness and efficiency of the space transportation industry
- A plan to upgrade existing test capabilities and acquire new space transportation facilities to meet the test requirements of expanding technology validation and system development programs

Note that many of these topics may have been addressed by other recently completed or ongoing studies by groups sponsored by NASA and other federal agencies. For the materials and structures community, follow-on activities should be aware of the

results established by these other efforts, and maximize the use of this information.

Communications

Current activities should catalyze communications *within* the materials and structures community and *between* it and the broader space transportation community. Improvements in communications between the developers and users of space technology are particularly important.

Industry Participation

Industry participation is a key aspect of continuing activities. Specific examples of industry's ability to enable the application of materials and structures technologies in the future include the following:

- Demonstration of the payoff of advanced materials and structures in terms of performance and safety
- Participation in a top-down analysis of requirements for non-destructive evaluation and their relation to launch activities
- Identification of key issues related to nuclear propulsion and assistance to ensure that proposed research activities take full advantage of prior nuclear propulsion research and development
- Coordination of research activities within the aerospace industry and between industry, government and academia to avoid duplication of research efforts
- Space system primes' identification of alternative fabrication processes for future ELV's and other space vehicles

As much as possible, continuing activities should be structured to fully incorporate the perspective of *all* relevant parties on issues of interest. Participation from the Department of Energy, Department of Defense, SDIO, other government agencies, academia and professional organizations is necessary to develop and implement key materials and structures technologies for space transportation.

APPENDICES

***Space Transportation
Structures and Materials Technology Workshop
Omni Hotel, Newport News, Virginia***

September 23-26, 1991

Monday - September 23, 1991

9:00 a.m. - 1:00 p.m. **Check In:** Badging; Final Agenda; Banquet Tickets; Information

Session 1 - Workshop Overview

1:00 p.m. - 1:10 p.m.	Welcoming Remarks	Charles Blankenship (LaRC)
1:10 p.m. - 1:30 p.m.	Headquarters Perspective, Office of Space Flight	Ron Harris (Hdqrs., Code MD)
1:30 p.m. - 1:50 p.m.	Headquarters Perspective, Office of Aeronautics, Exploration and Technology	Greg Reck (Hdqrs., Code RS)
1:50 p.m. - 2:00 p.m.	Introduction to Sessions 2 through 5	Del Freeman (LaRC)

Session 2 - Earth-to-Orbit Cargo Systems

2:00 p.m. - 2:20 p.m.	Cargo Vehicle Architecture Options	Gene Austin (MSFC)
2:20 p.m. - 2:50 p.m.	NLS Structures and Materials	Dr. Jack Bunting (Martin-Denver)
2:50 p.m. - 3:10 p.m.	Break	

Session 3 - Manned Earth-to-Orbit Systems

3:10 p.m. - 3:40 p.m.	Advanced Manned Launch System	Dr. Ted Talay (LaRC)
3:40 p.m. - 4:10 p.m.	ACRV/PLS	Jerry Craig (JSC)
4:10 p.m. - 4:35 p.m.	Single Stage to Orbit/SDIO	Jim French (SDIO)
4:35 p.m. - 5:00 p.m.	National Aero-Space Plane	Dr. Terence Ronald (NASP)
5:00 p.m.	Adjourn	
6:00 p.m.	Social	
7:30 p.m.	Banquet	
	U. S. Competitiveness: The Rules of the Game	Dr. Will Stackhouse, (USAF Space Division)

Tuesday - September 24, 1991

Session 4 - Manned Transfer Vehicles

8:00 a.m. - 8:30 a.m.	Lunar Transfer Vehicle Studies	Joe Keeley (Martin-Denver)
8:30 a.m. - 9:00 a.m.	Mars Transfer Vehicle Studies	Gordon Woodcock (Boeing-Huntsville)
9:00 a.m. - 9:20 a.m.	Aerobrake Technology Studies	Chuck Eldred (LaRC)

Session 5 - Advanced Propulsion

9:20 a.m. - 9:50 a.m.	Earth-to-Orbit Rocket Propulsion	Steve Gentz (MSFC)
9:50 a.m. - 10:10 a.m.	Advanced Rocket Propulsion	Chuck O'Brien (Aerojet)
10:10 a.m. - 10:30 a.m.	Break	
10:30 a.m. - 10:50 a.m.	Space Propulsion	John Kazaroff (LeRC)
10:50 a.m. - 11:20 a.m.	Nuclear Concepts/Propulsion	Tom Miller (LeRC)
11:20 a.m. - 11:40 a.m.	Solid Propulsion	Dr. Ronn Carpenter (Thiokol)
11:40 a.m. - 12:00 noon	Combined Cycle Propulsion	Dr. Terence Ronald (NASP)
12:00 noon - 1:00 p.m.	Lunch	

Session 6

1:00 p.m. - 1:30 p.m.	Charge to Panels	Sam Venneri (Hdqs., Code RM)
1:30 p.m. - 2:00 p.m.	Charge to Panels	Chet Vaughan (Hdqs., Code MZ)

Session 7

2:00 p.m. - 5:00 p.m.	<u>Panels Convene:</u> Vehicle Systems Materials and Structures Entry Systems Materials and Structures Propulsion Systems Materials and Structures	Ballroom D Ballroom C Amphitheatre, Junior Ballrooms 2,3
5:00 p.m.	Adjourn	

Wednesday - September 25, 1991

Session 8

8:30 a.m. - 12:00 noon

Panels Convene:

Vehicle Systems Materials and Structures

Reusable Vehicles	Ballroom C
Expendable Launch Vehicles and Cryotanks	Ballroom D

Entry Systems Materials and Structures

Earth to Orbit/Orbit to Earth	Room 901
Earth to Planet/Planet to Earth	Room 911

Propulsion Systems Materials and Structures

Liquid Propulsion	Junior Ballroom 2
Solid Propulsion	Amphitheatre
Nuclear Propulsion	Junior Ballroom 3

12:00 noon - 1:00 p.m.

Lunch

Session 9

1:00 p.m. - 5:00 p.m.

Panels Convene:

Vehicle Systems Materials and Structures

Reusable Vehicles	Ballroom C
Expendable Launch Vehicles and Cryotanks	Ballroom D

Entry Systems Materials and Structures

Earth to Orbit/Orbit to Earth	Room 901
Earth to Planet/Planet to Earth	Room 911

Propulsion Systems Materials and Structures

Liquid Propulsion	Junior Ballroom 2
Solid Propulsion	Amphitheatre
Nuclear Propulsion	Junior Ballroom 3

5:00 p.m.

Adjourn

7:00 p.m.

The following rooms have been reserved
for evening sessions if needed

Propulsion Systems Materials and Structures	Amphitheatre
Entry Systems Materials and Structures	Junior Ballroom 2
Vehicle Systems Materials and Structures	Junior Ballroom 3

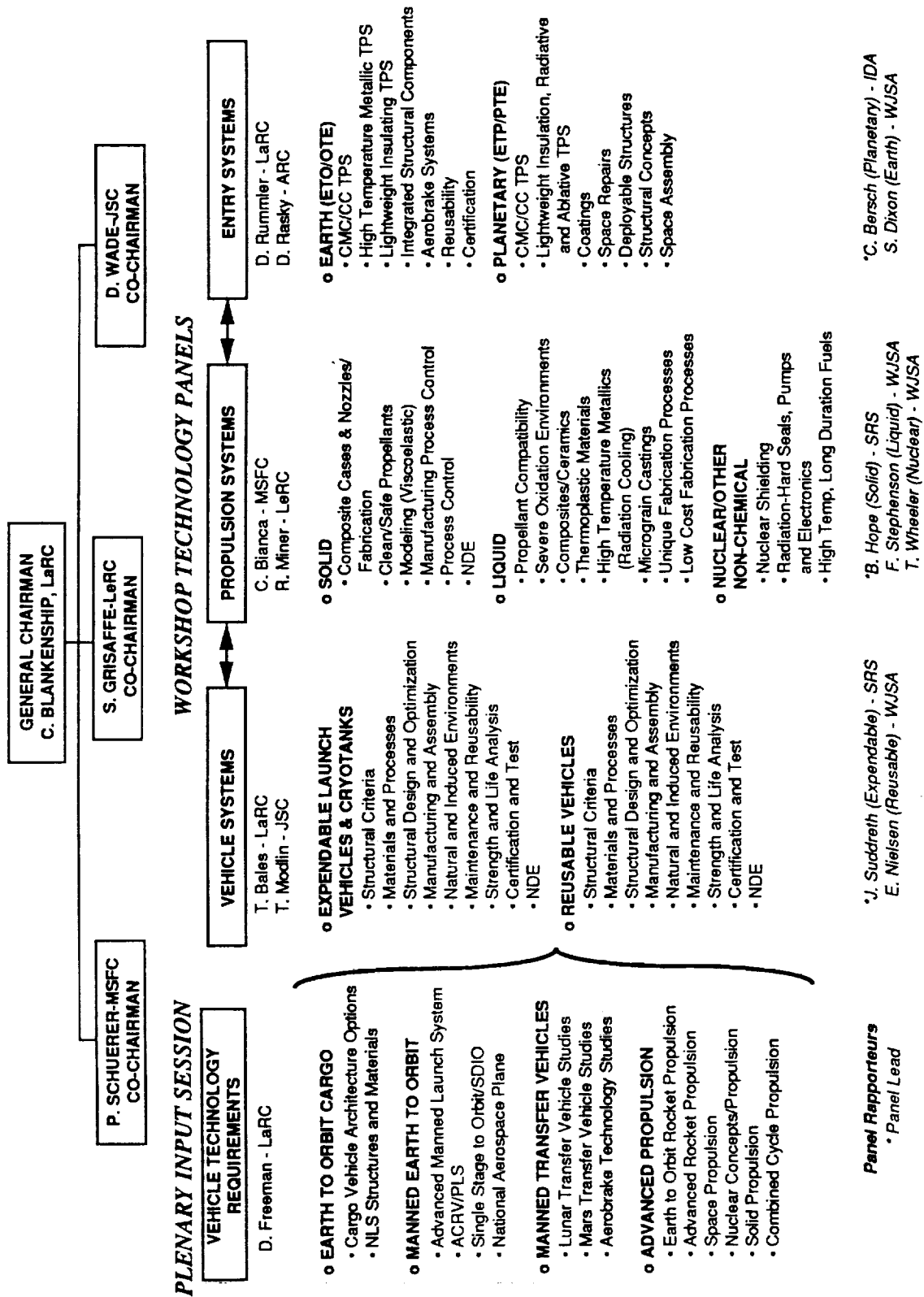
Thursday - September 26, 1991

Session 10: Panel Reports

8:30 a.m. - 9:00 a.m.	Vehicle Systems Panel Report	Tom Bales (LaRC) Tom Modlin (JSC)
9:00 a.m. - 9:30 a.m.	Propulsion Systems Panel Report	Carmelo Bianca (MSFC) Bob Miner (LeRC)
9:30 a.m. - 10:00 a.m.	Entry Systems Panel Report	Don Rummmler (LaRC) Dan Rasky (ARC)
10:00 a.m. - 10:30 a.m.	Break	
10:30 a.m. - 12:00 noon	Open Forum	Charles Blankenship
12:00 noon	Workshop Concludes	

SPACE TRANSPORTATION MATERIALS & STRUCTURES TECHNOLOGY WORKSHOP

Panel Structure & Topics



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13. ABSTRACT (Maximum 200 words) The Space Transportation Materials and Structures Technology Workshop was held on September 23-26, 1991, in Newport News, Virginia. The workshop, sponsored by the NASA Office of Space Flight and the NASA Office of Aeronautics and Space Technology, was held to provide a forum for communication within the space materials and structures technology developer and user communities. Workshop participants were organized into a Vehicle Technology Requirements session and three working panels: Materials and Structures Technologies for Vehicle Systems, Propulsion Systems, and Entry Systems. The threefold workshop goals accomplished were (1) to develop important strategic planning information necessary to transition materials and structures technologies from laboratory research programs into robust and affordable operational systems; (2) to provide a forum for the exchange of information and ideas between technology developers and users; (3) to provide senior NASA management with a review of current space transportation programs, related research, and specific technology needs. The workshop thus provided a foundation on which a NASA and industry effort to address space transportation materials and structures technologies can grow.				
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